Plans for wave basin tests of the Floating Power Plant P80 device under the OESA project and the EUDP O&G project

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Carried out for:

Floating Power Plant A/S

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Abstract

Floating Power Plant is, together with several partners, preparing to design, build and test a scaled version of the complete so-called P80 device. The scaled model is to be tested in AAU's wave basin, SSPA's facilities, followed by at least one external facility. The model will be tested in combinations of wave, wind and current conditions with a view to validating the numerical models and to further develop the understanding of the interactions within the device. The purpose of this document is to gather information that is relevant to designing and building the physical scaled model, and to designing and executing the test campaign.

Version

Version	Date	Description of Change
1d	2020-05-29	First issue with some minor corrections (Ver1a..Ver1d).
2	2020-06-12	Update according to progress. This includes especially the design and construction of the new wave PTO which was finished since the first version. New additions: Much more details regarding the new wave PTO, proposal for ballast of absorber, update with two additional requirements to the model (first two bullets in section 2.2: Water tight model, non-corrosive materials), minor update of the status in section 1.
3	2020-09-01	Update with a small correction: Model is being constructed at Aston Harald and not at Kaltech as originally planned.

Contents

1 Introduction

As part of the EUDP project "De-carbonisation of Oil & Gas Production – by cost effective Floating renewable Technologies, J.nr. 64019-0833" (abbreviated as the *O&G project*) testing in the wave basin at Aalborg University (AAU) is planned to take place in the 2nd half of 2020, starting by the end of August at the earliest. Further tests are planned in the Interreg supported OESA project, which most likely will take place in 2021.

Testing is planned to be with a complete small-scale model of the Floating Power Plant (FPP) so-called *P80 platform*. The overall scope of the tests on this new model, which will take place in various facilities, is to demonstrate the performance of the device in combined wind, waves and currents. The purpose of this document is to provide information about the AAU wave basin facility in order to start designing of the model including decide on the mooring layout and specifications. The overall plan for the model building and testing is:

1) Decide on overall model specifications, Table 1
2) Design of model (small-scale)
3) Construction of model
4) Testing at various facilities
5) Analysis and documentation of results

To accomplish the first bullet the following tasks in Table 1 must be decided based on the P80 design. Some of the tasks and information is given in the current report.

Table 1. Overall model specification tasks.

Task	Status by current report version (12 June 2020)
Define outer geometrical shape of platform and absorber hull	Finished by 12 May 2020 as the so-called "Design freeze May 2020" [1]
Decide on possible wind turbine to put on model	Completed by 11 June 2020. Intention is to include a modified version of the AAU wind turbine (WT) for initial tests with simple control [2], and later the IH Cantabria turbine for advanced control [3]
Mass, centre of gravity and inertia moment of platform, absorbers and wind turbine	Platform details are part of design freeze [1]. Absorber details will be documented by FPP, planned to be finished by 15 June 2020. Expected model scale WT mass details is included in current report. Model WT's are too light, so ballast will be applied to platform and/or WT.
Decision on PTO system to control the power extraction of the absorbers	Concluded by AAU on 14 May 2020 and described in the current report
Integration of sensors to measure forces and motions	Initial plans and ideas are described in the current report
Mooring system suitable for the relative low water depth in the basin at Aalborg University of 1.2 m	APL will provide inputs based on the descriptions in the current report
Decide on sensors and buy them	Initial plans and ideas are described in the current report
Test schedule and plans	Initial plans and ideas are described in the current report

The design of the model (bullet number 2 on the list above) will be coordinated by FPP, but performed by SSPA Sweden as part of the OESA Interreg project, with inputs and in collaboration with the model builder Aston Harald (Jens Allroth). The design was initiated at SSPA on 27 May 2020, and it will include design of ballast, internal structure to transfer loads and stiffen the device, absorber bearing arrangement, etc.

1.1 Background

The new testing is complementing extensive previous testing on the FPP device. Since 1998 Floating Power Plant (FPP) has performed physical testing at different scales both in controlled laboratory environments, and offshore in the less predictable natural environment. A complete thorough overview of the testing up to 2018 is found in [4], and a more recent brief update in [5].

The testing described in this report is, in particular, building on the experiences which were gained during the testing that was performed in 2015 to 2019 at Aalborg University plus some testing at Oceanide in France in 2017. Papers and presentations with some of the first results has been published [6]-[9], whereas a general overview of the most recent model, which was termed Absorber Mark IV, is given in [10]. Specific details of the model and the setup at Oceanide is given in [11]. Final reporting of some of the tests are still outstanding, although a draft report is available [12].

The planning of the current test campaign was kicked off during a meeting at SSPA on 24th of October 2019 as described in [13]. The current report is an extension of the work [ibid.].

1.2 Overall test plans

The testing periods are still in the planning phase with the overview given in Table 2.

Table 2. Overall test plan with the new FPP P80 1:30 scale device.

Planned period	Facility	Funding	Main purpose/description
October/November 2020	AAU	EUDP O&G project (AAU budget)	Ensure basic model performance (flotation level, working WT, working WEC & PTO, …), and perform simple initial tests like decay, non-combined simple wave tests, current tests, wind-tests.
Late 2020, early 2021	SSPA	OESA project (SSPA budget)	Detailed towing tests, detailed wave tests at large depth, detailed combined wave and towing tests
Spring 2021	IH Cantabria or other large basin	OESA project (FPP budget) and/or possibly Marinet 2	Detailed tests at large water depth with combined currents, waves and winds. Focus on WTG control and platform interaction.
Late 2021	AAU	OESA project (AAU budget)	Tests on new/updated model (final design to be constructed). Detailed and dedicated tests for numerical model validation with focus on WEC PTO control and platform interaction.
Late 2021/2022	Large facility	OESA project (FPP budget)	Tests on new/updated model (final design to be constructed) at large facility with combined wind, waves, current.

Further details about the test programme for the first three test campaigns are given in Section 5. The 4th and final test campaign on the list is planned to take place with an updated or new model, which is yet to be decided.

1.3 Main Aims

The main aim of the test campaigns to validate and obtain:

1. **Horizontal Drag Coefficients (*Cd*)** of the complete P80 (with fixed WECs) at different headings
   For input into numerical models for the force due to current at different headings, and the horizontal drag forces opposing the motion of the platform
2. **Turning moment due to waves at different headings**
   In the numerical models this is currently approximated be the mean second order drift forces
3. **Turning moment due to operating WECs at different headings** (with different PTO settings)
   This isn’t presently included in the numerical model but is planned to be included as a mean second order drift force for active WEC. This method is unclear for now.
4. **Motion responses of platform and absorbers including WEC power absorption** under realistic platform motions subject to simultaneous wind, wave and current
   This is generally needed to validate the numerical models.
5. **Heading of the platform in misaligned wave, wind and current directions**
6. **Mooring loads**
7. **WEC absorber loads (PTO loads and absorber bearing loads)**

1.4 Core personnel/partners

The main persons involved in the planning and testing is given in Table 3.

Table 3. List of main personnel involved in the testing.

<table>
<tr><th>Name</th><th>Company/Organisation</th><th>Relevance/Specialism</th></tr>
<tr><td>Sarah Thomas</td><td>Floating Power Plant A/S</td><td>Device developer lead</td></tr>
<tr><td rowspan="2">Morten Kramer</td><td>Aalborg University</td><td rowspan="2">Wave energy device specialist; Has performed many of FPP’s previous scaled tests</td></tr>
<tr><td>Floating Power Plant A/S</td></tr>
<tr><td>Nis Ebsen</td><td>Floating Power Plant A/S</td><td>Electrical connections and sensors</td></tr>
<tr><td>Pilar Heras</td><td>Floating Power Plant A/S</td><td>3D CAD drawings as-built</td></tr>
<tr><td>Jacob Andersen</td><td>Aalborg University</td><td>Will be working on FPP R&D over the next couple of years. CFD specialist</td></tr>
<tr><td>Michael Leer-Andersen</td><td>SSPA</td><td>SSPA facility lead</td></tr>
<tr><td>Anders Esbjörnsson</td><td>SSPA</td><td>Will design and draw the scaled model</td></tr>
<tr><td>Jens Allroth</td><td>Aston Harald</td><td>Will build the scaled model</td></tr>
<tr><td>Geir Olav Hovde</td><td>APL</td><td>Main designer of full-scale turret and mooring; Will design mooring for scaled tests</td></tr>
<tr><td>Raúl Guanche</td><td>IH Cantabria</td><td>Investigate the possible use of IH Cantabria model scale wind turbine</td></tr>
</table>

2 Model overview, requirements & instrumentation

The model will be a scale 1:30 of the complete FPP P80 platform, and it is therefore intended to include all the key components of the device as given in Figure 1, except for the subsea grid.

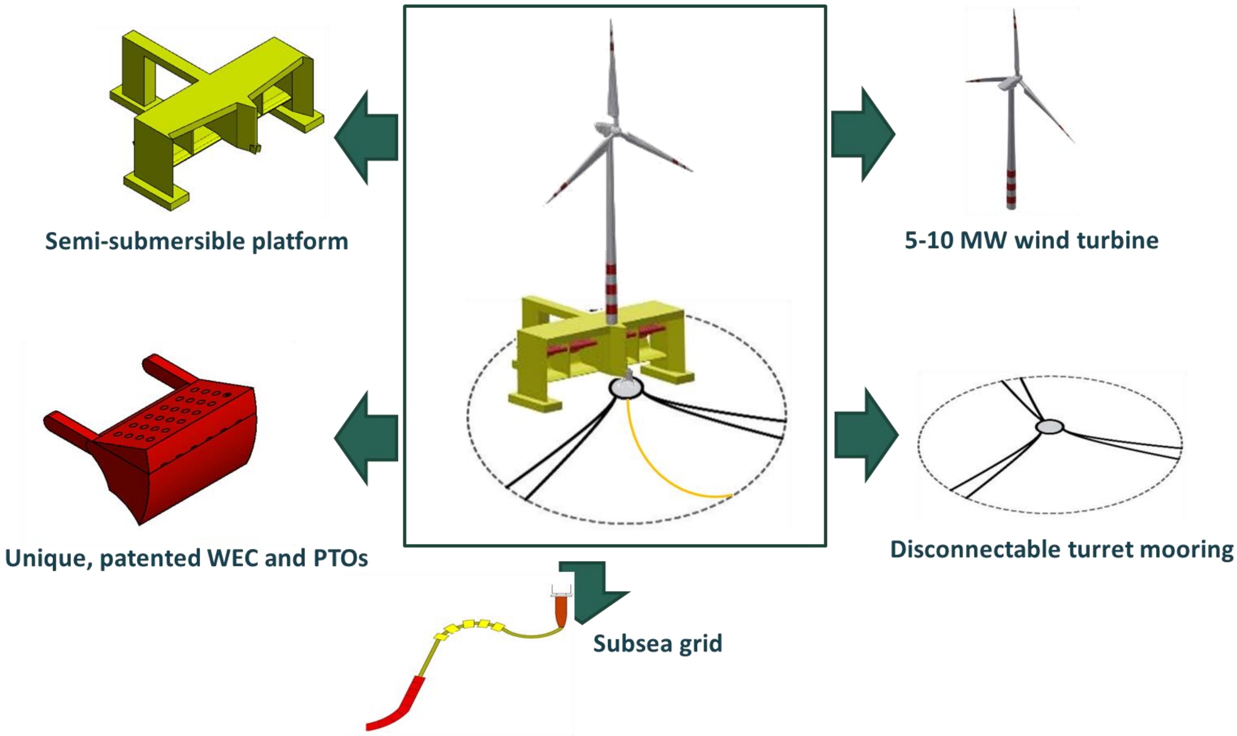


Figure 1. Floating Power Plant P80 key components.

The P80 is moored using a turret mooring located at the front of the semisubmersible central hull. In misaligned wind and wave conditions, the wind turbine will yaw mechanically to face the wind, whilst the platform will rotate passively around the turret mooring position in yaw to face the wave direction. In misaligned wave and current directions, the platform may face an intermediate yaw heading, between the waves and currents (depending of the energy in the waves and strength of the current). The first tests will NOT include an active yawing mechanism of the turbine, but a manual mechanism will be included that allows the WT to be rotated between tests.

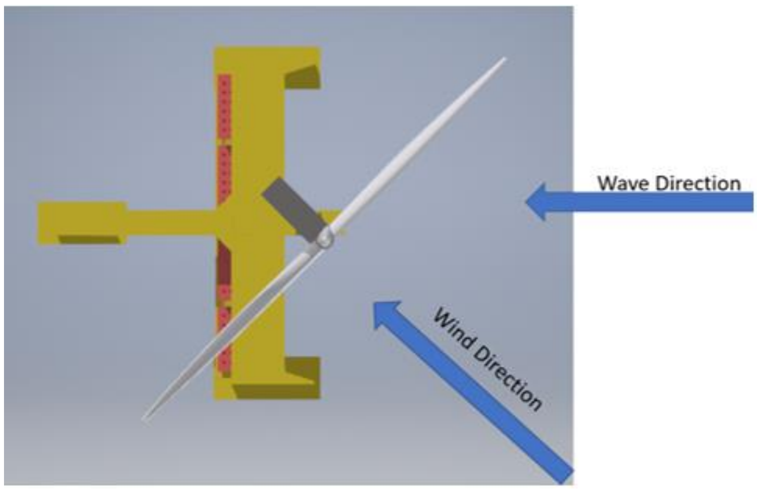


Figure 2. The P80 platform rotates passively in yaw about the turret mooring position to face the wave direction, whereas the wind turbine yaws mechanically to face the wind direction.

2.1 Reasons for choosing the model scale 1:30

The model scale was chosen due to the reasons given in Table 4.

Table 4. Reasons for choice of model scale.

Reasons for a large model	Reasons for a small model
Scale effects are reduced	The model should be possible to handle at the facilities by crane, and transportation should be possible in a van
Model geometry production accuracy and sensor accuracy is increased	Mooring system and water depth is more accurately representing the full-scale design
Visually a larger model is better for demonstration	Price is reduced
	Testing time is reduced as handling is quicker, and sea states are shorter at smaller scale

The scale of the new model is chosen to be 1:30 as that is assessed to give a good balance between the pros and cons given in Table 4. The previous FPP small scale models which were tested at AAU and Oceanide were also scale 1:30, and they worked fine [4]-[12].

2.2 List of requirements for the model

The following is an initial (non-exhaustive) list of required specifications to the model:

- Model must be water tight, and constructed so that materials and inner compartments don't absorb water during testing in wave basin (mass must remain constant)
- All materials must be non-corrosive (stainless steel, aluminium, plastic, fibre, ceramic, …)
- Possibility for fine-tune adjustment of draft, trim and heel by ballasting
- Possibility to ballast both the WA in storm protection mode and WA in operational mode
- Possibility to yaw the WT relative to the platform (a manual mounting system where the WT can be placed in fixed angles, possibly with 15.0 or 22.5 degree steps)
- Freely yawing-system by the mooring turret should be included (e.g. using low friction bearings)
- Possibility to disconnect mooring lines by the turret
- Hooks on platform top to enable lifting of the complete model by crane
- Mounting points at port and starboard side at the stern of the platform, giving the option to mount mooring lines enabling tests where the motions in yaw are restricted (fixed in yaw). The stability to avoid pitch and roll motions should be considered when deciding on vertical positions, number of mounting points and the external locations to fix the lines
- Model should be able to be spilt in a few large parts to enable transportation in a large van
- It should be possible to remove and install absorbers individually
- Locking of individual absorbers at any position should be possible
- Instrumentation should be included in the design-phase, as some equipment is heavy (e.g. PTO systems, force sensors)
- Low friction stainless steel ball bearings (or similar low-friction bearings) should be used for absorbers

2.3 Instrumentation of model

Equipment, which so far is decided:

- At least 10 free surface wave gauges (provided by facility)
- Optical motion tracking of platform, 6 dof, using Qualisys system (provided by facility)
- Optical motion tracking of a single freely moving absorber (no actuator), 6 dof, using Qualisys system (provided by facility)
- Video recording system (provided by facility)
- One load cell per mooring line (provided by facility)
- Forces between absorber and PTO system, to be measured by 1 dof force sensors between PTO pistons and absorber (possibly provided by AAU)
- PTO systems with controllers, actuators, computers etc (provided by AAU, maybe partly by FPP), see Section 2.3. The system includes measurement of relative motions between absorbers and platform, which will be measured by motion sensors in the PTO pistons
- Forces between main absorber bearings and platform are of major interest (bearing forces). Dedicated load pins could possibly be an option (if they exist at this small scale, this is a subject for further investigation). SSPA will come up with a proposal for a design.
- Force sensor (6 dof) for measurement of WT forces. The sensor will be placed just under the nacelle. i.e. at the top of the WT tower. AAU will provide the sensor for tests with the AAU turbine. IHC will provide their own sensor to be used with the IHC WT.

2.4 Ballasting of platform and wind turbine

The model motions are considered as rigid body motions. This means that the turbine is also considered stiff, and potential flexibility of the tower is not considered. The wind turbine and the platform can thereby be considered as one structure regarding the mass details: Total mass, centre of gravity (CoG) and inertia moments, i.e. often given as a mass matrix and CoG.

Mass details for the DTU-10MW wind turbine are given in [1] and the down-scaled model-scale mass is given in Table 5. It is seen that the total mass of the turbine at model-scale is almost 46 kg.

Table 5. Mass distribution for DTU-10MW wind turbine at full-scale [1], and model scale. VCG is with reference to deck.

	Full-scale		Down-scaled to model	
	Mass (tonnes)	VCG (m)	Mass (kg)	VCG (m)
Tower adjusted to P80	556	41	20.6	1.4
Nacelle	446	103	16.5	3.4
Rotor (blades + hub)	231	103	8.6	3.4
Total mass	1233	75.2	45.7	2.5

The FPP model is constructed such it is suitable for switching wind turbines. The use of two different turbines are planned:

1) "WT AAU". WT designed by Morten Kramer at AAU, capable of delivering high thrust, a WT that can follow the model to different tests and demo
2) "WT IHC". WT designed by IH Cantabria (the one by Tommaso). This WT is capable of advanced control and regulation. We will rent it for short durations for dedicated use at Cantabria or other large scale basin

Tower and connection to platform will be the same for both WTs. Further, the connection for both WTs will be the same with a flange near the top of the tower. The tower itself will be a Ø160 mm alu pipe, 5 mm thickness. (https://www.sanistaal.com/da/produkter/staal-og-metaller/aluminiumsroer-og-profiler/aluminiumroer-runde/c-10.124.70/1773365/aluminiumsroer-rund-en-aw-6060-t6)

In Table 6 the expected mass of the model scale AAU turbine is given (the construction is ongoing at the moment, so final as-built values are unknown). Mass of the IH Cantabria turbine is expected to be approximately the same.

Table 6. Expected mass of turbine at model scale (AAU turbine). VCG is with reference to deck.

	Model expectation (AAU turbine)		
	Mass (kg)	VCG (m)	Notes
Tower adjusted to P80	22.3	1.70	
Flange in bottom connecting tower to platform	0.8	0.05	
Connection between tower and load sensor	1.0	3.40	
Force sensor, 6 axis	2.7	3.40	
Cable for force sensor	0.3	2.00	Rough estimate
Flange and mount for motor-system	0.4	3.40	
Motor & ESC & controller etc	1.0	3.40	
Cable for motor (power + control)	0.3	2.00	
Total excluding possible ballast	28.9	1.96	
Possible ballast in small scale	16.8	3.4	To de decided depending on design of platform (preferable we would like to avoid this extra ballast)
Total mass	45.7	2.49	

The model scale WT is too light (about 29 kg) and additional mass of about 17 kg of ballast is needed if the total scaled down WT weight (46 kg) must be matched. These 17 kg can be put on the platform or on the WT, wherever it is preferred regarding the total vertical CoG and inertia moment of the combined platform+WT.

The model designer (SSPA) will decide on whether the turbine should be ballasted or just the platform, as he is also in charge of the design of the platform mass distribution and ballasting.

2.5 Ballasting of absorber

The absorber ballast must be constructed such that two conditions can be satisfied:

- Absorber in operational, where the absorber is floating at the operational rest position
- Absorber in storm protection, where the absorber is heavily ballasted to sink, such the absorber rests on the platform (bottom plate in chamber). When at this position the absorbers will further be mechanically locked, e.g. by the using the PTO piston.

As the absorbers are moving relative to the platform, the mass details for the absorbers in operation must be scaled correctly from the full-scale expectations. The way the ballasting was performed previously was by applying steel rods into dedicated ballast holes, which were accessible via sealed plastic lids located on the top of the absorber. This allowed both adjustment of mass, CoG and the pitch inertia moment of the absorber. Similar ballasting system is suggested for the new model.

In the previous model vertical ballast holes of diameter 28 mm were drilled into main absorber body. Different ballast cases were obtained though positioning specific numbers of stainless steel cylinders (ballast pieces) in specific ballast holes. Each ballast piece has a diameter of 28 mm and height of 49 mm. Details on the blocks are given in Table 7.

Table 7: Details on weight of blocks, previous model.

Details of weight blocks				Details of plastic blocks				
				Type	Mass		Length	
				B1	0.1448	kg	160	mm
10 weight blocks:		2372	g	B2	0.1715	kg	189	mm
One weight block:		0.2372	kg	B3	0.0796	kg	88	mm

The model was made with two rows of ballast holes, and inner row and an outer row, and different numbers of ballast pieces (1 to 4 pieces) were put in the holes to adjust the ballast, see Figure 3.

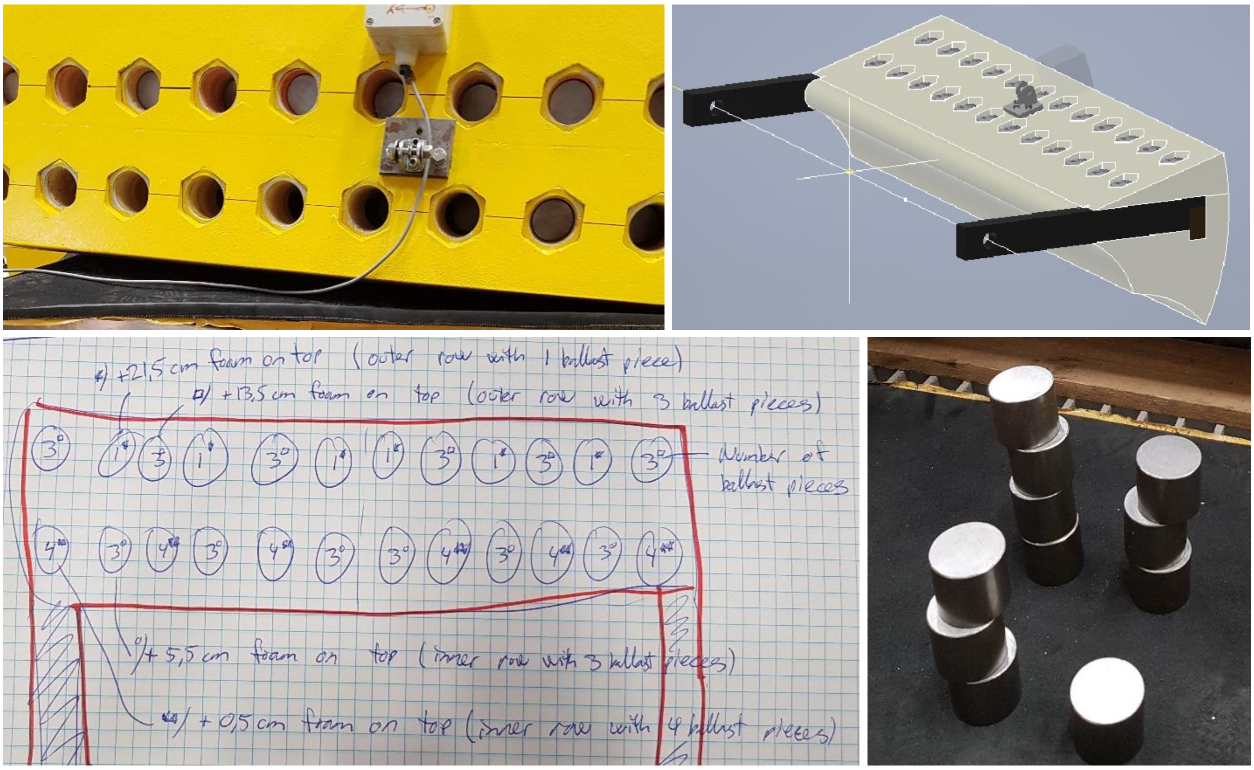


Figure 3. Ballasting of model, previous absorber.

2.6 PTO System

A similar, but smaller, system as used in the previous small-scale tests with the FPP models are used [3,9]. This system has proved accurate and robust. Each absorber is equipped with an electrical linear actuator and a controller. Data from all absorbers are collected and controlled from a single PC, which communicate with the systems through a data acquisitions system. Measurements of motions are performed by an internal position encoder in the actuator, and forces are measured by a strain gauge force transducer. The computer software can in principle apply any force or motion (within some wide ranges) using a given control strategy. A sketch of the hardware used for the control is shown in Figure 4, and the connection of the PTO between the absorber and the platform is shown in Figure 5 for the model used previously.

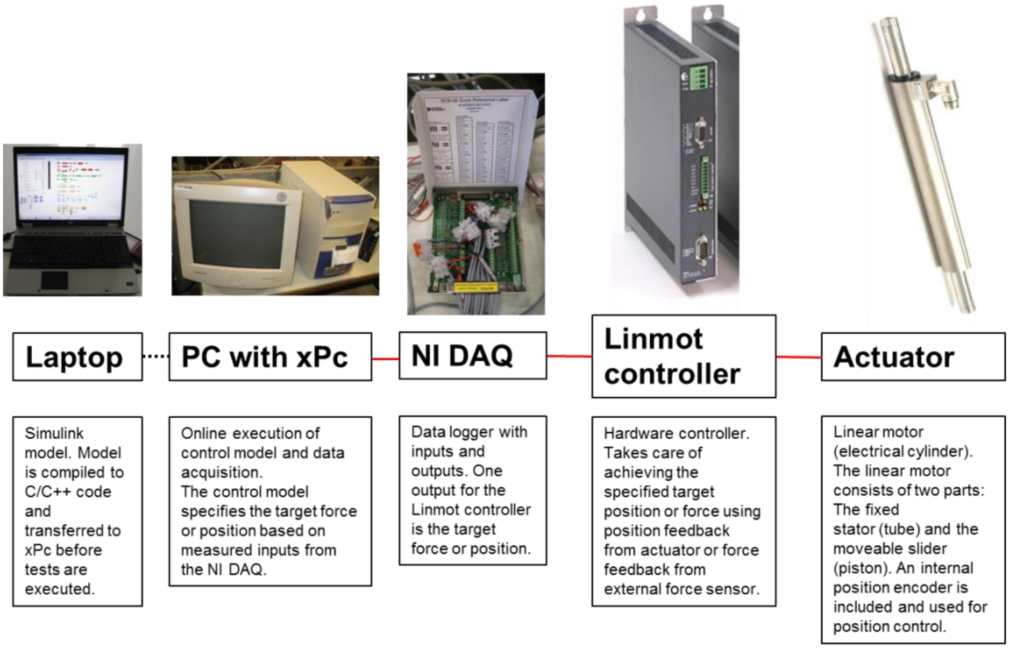


Figure 4. Sketch of control hardware using the linear actuators.

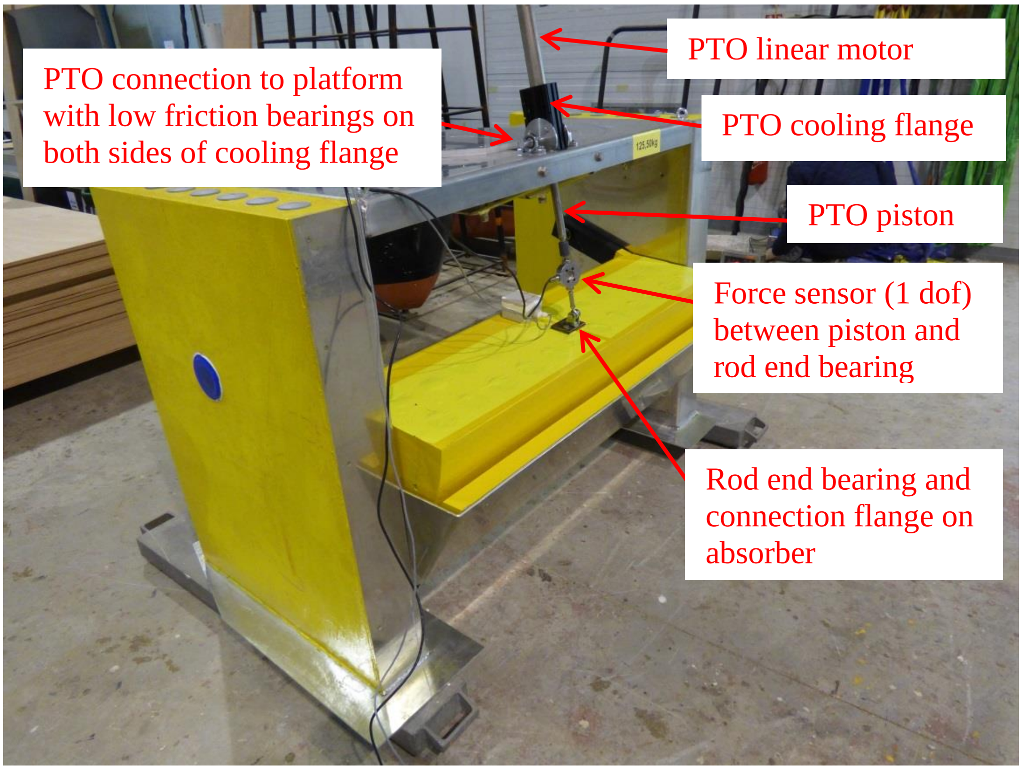


Figure 5. Overview of PTO connections between absorber and platform, previous model.

Details on the PTO connection is shown in Figure 6. Note that the actuator system is going through the upper deck of the platform and is mounted with bearings on both sides of the cooling flange at the top of the deck.

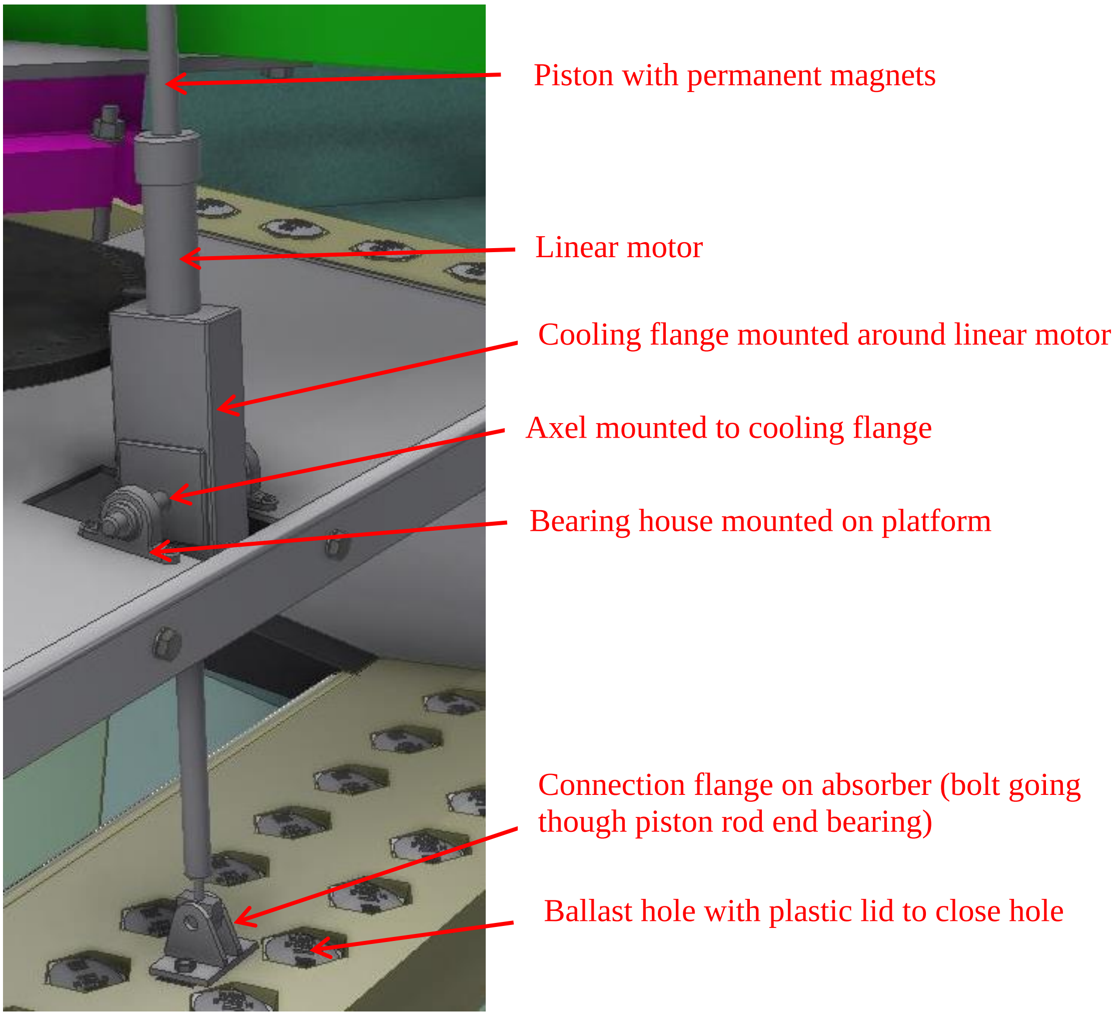


Figure 6. PTO connection details, previous model.

When the absorber moves up and down it is making pitching motions about the absorber bearing, which is termed bearing point A. The PTO house is mounted with bearings on the platform which is termed bearing point B. As the absorber moves up the PTO piston is also moved up and so is the cylinder rod end bearing point C on the absorber. The motion is described in the absorber coordinate system which is fixed to the platform with origo at the absorber bearing point A. The relation between absorber motion and piston extension is found by geometrical relations in the triangle with the corners A, B & C. The bearing point locations used for previous model tests is shown in Figure 7, and the motion of the actuator applied for these positions to the new design is shown in Figure 8. Point A & B is fixed in space (fixed to platform), and only the point C is moving along a circular path as indicated in Figure 8.
In Table 8 and Table 9 the geometrical formulae and the relation between absorber angle and piston length is given. As an example the minimum piston stroke is found from the last line in Table 9 to be 365 mm (range of ℓ_{BC}), which is suitable for the new actuator system.
The bearing coordinates used for the previous design has been used in the given figures and tables. These points can be used as indicative for deciding the points on the new model. Some difference in the points (say in the order of cm) is acceptable for the new model. Herby positions which are suitable for the fixations to the new platform and absorber can be chosen. However, to ensure no problems the motion of the actuator and piston should be checked when the exact new locations of the bearings are decided.

Point	X (mm)	Z (mm)	Radius (mm)	Angle (°)
A: Bearing on platform for absorber (fixed)	0	0	0	
B: Bearing on platform for cylinder (fixed)	364.5	441	572	50.4
C: Bearing on float for cylinder rod-end (horizontal)	418.9	126.2	437	16.8

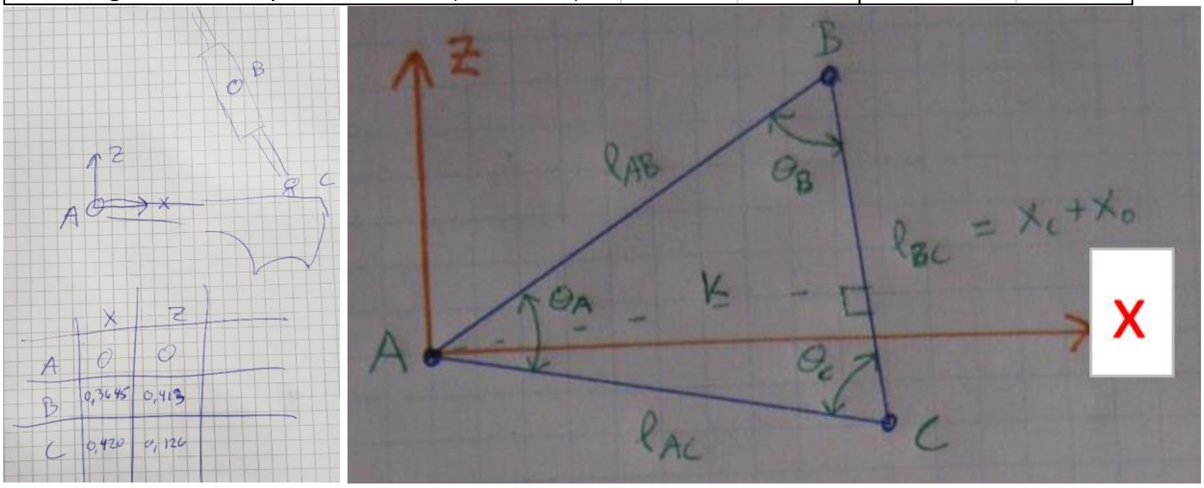


Figure 7. PTO connection coordinates, previous model. Exact coordinates are to be updated for the new design.

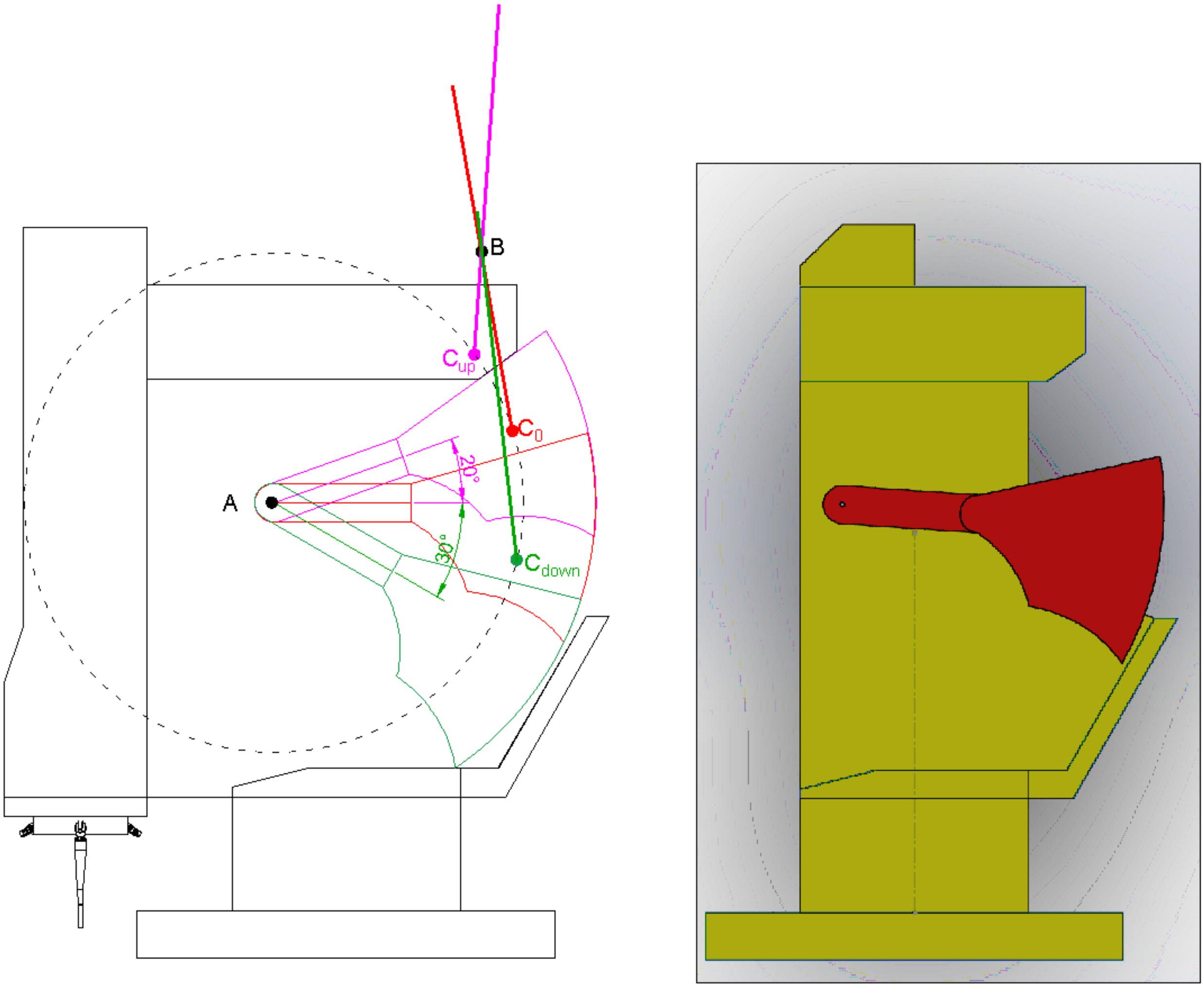


Figure 8. Absorber and PTO piston motion. PTO piston is shown with thick lines going from bearing point C on the absorber and through bearing point B on the platform. Range is shown on left: Green absorber at -30° downward hitting bottom box, Red absorber at 0° with horizontal arm, purple absorber at 20° upward hitting upper platform deck. Right: "Clean" image of absorber at neutral buoyancy with rest angle at about -4°.

Table 8. Constants calculated by geometrical relations and bearing points given in Figure 7. Exact coordinates are to be updated for the new design.

ℓ_{AB}	572	mm
ℓ_{AC}	437	mm
$\ell_{BC,0}$	319	mm
K_0	434.27	mm
$\theta_{A,0}$	33.66	°
$\theta_{B,0}$	49.38	°
$\theta_{C,0}$	96.96	°

1) $\theta_{A,0} = Acos\left(\frac{x_C}{\sqrt{x_C^2+z_C^2}}\right) - Acos\left(\frac{x_B}{\sqrt{x_B^2+z_B^2}}\right)$

2) $\theta_A = \theta_{A,0} + \theta_{absorber}$

3) $\ell_{BC} = \sqrt{\ell_{AB}^2 + \ell_{AC}^2 - 2\ell_{AB}\ell_{AC}\cos\theta_A}$

4) $K = \frac{\ell_{AB}\ell_{AC}}{\ell_{BC}} \cdot \sin\theta_A$

5) $\theta_B = Asin\left(\frac{K}{\ell_{AB}}\right)$

6) $\theta_C = Acos\left(\frac{\ell_{AC}^2 + \ell_{BC}^2 - \ell_{AB}^2}{2\ell_{AC}\ell_{BC}}\right)$

Table 9. PTO piston motions based on formulae in Table 8. Exact coordinates are to be updated for the new design.

		Formula number (1st line) and parameter (2nd line)				
		2	3	4	5	6
	$\theta_{absorber}$ (°)	θ_A (°)	ℓ_{BC} (mm)	K (mm)	θ_B (°)	θ_C (°)
Upper position	20	13.7	180	329	35.1	131.2
	18	15.7	192	353	38.0	126.3
	16	17.7	204	372	40.5	121.8
	14	19.7	218	387	42.6	117.8
	12	21.7	231	400	44.3	114.1
	10	23.7	245	409	45.7	110.7
	8	25.7	260	417	46.8	107.5
	6	27.7	274	423	47.7	104.6
	4	29.7	289	428	48.4	101.9
	2	31.7	304	432	49.0	99.4
Horizontal float	0	33.7	319	434	49.4	97.0
	-2	35.7	335	436	49.7	94.7
	-4	37.7	350	437	49.8	92.5
	-6	39.7	365	437	49.9	90.5
	-8	41.7	380	437	49.9	88.5
	-10	43.7	396	437	49.8	86.6
	-12	45.7	411	436	49.6	84.7
	-14	47.7	426	434	49.4	83.0
	-16	49.7	441	432	49.1	81.2
	-18	51.7	456	430	48.8	79.6
	-20	53.7	471	428	48.4	77.9
	-22	55.7	486	425	48.0	76.3
	-24	57.7	501	422	47.6	74.8
	-26	59.7	516	419	47.1	73.3
	-28	61.7	530	416	46.6	71.8
Lower position	-30	63.7	545	412	46.0	70.3
Range = abs(Upper position - Lower position)	50	50.0	364.9	82.9	10.9	60.9

For the new setup existing controllers owned by AAU will be used. Only new actuator systems will be used. To limit the weight of the PTO, smaller Linmot actuator pistons, motors and cables has been specifically designed and ordered for the purpose. Details are given in Table 10 and Table 11. In Table 12 the capability and estimated weight of the previous system is compared to the new system. The weight of the new system will only be about 2 kg per absorber (total 8 kg), whereas the previous system was three times heavier. The new system is about three times weaker than the previous system, but an analysis has shown that the capacity of the new system is sufficient.

Table 10. Price offer and model numbers for the 4 new Linmot actuators systems.

Nummer	Beskrivelse	Antal	Enhed	Pris	Rabat%	Beløb
LM-0150-1235	STATOR PS01-23x160F-R stator with IP67 connector M17/9(m)	4,00	Styk	4.579,25		18.317,00
LM-0150-2586	SLIDER PL01-12x480/440-LC Slider standard LC	4,00	Styk	3.185,50		12.742,00
LM-0150-2117	PF02-23x170 flange 23x170 mm Projektnummer 889086, EUDP 2019-I FPP O&G	4,00	Styk	531,25		2.125,00
LM-0150-3336-15	KR05-W/R-15 Special cable KR05-W/R-15 15m	4,00	Styk	4.202,75	20,00	13.448,80

Table 11. Details on the Linmot actuators ordered for the current tests.

PL01-12x480/440-LC

Slider 'standard LC'

Article no.: 0150-2586

Stroke Range	SS / ES
P0x-23x80	350 / 410 mm
P01-23x160	270 / 410 mm

Mechanical Data	
Length	480 mm
Diameter	12 mm
Through bore-hole	no
Mass	390 g

PS01-23x160F-R

Stator with IP67 connector M17/9(m)

Article no.: 0150-1235

Technical Data	
Max. Stroke	780 mm
Max. Force	86 N
Continuous Force	16/30 N
Max. Velocity	6 m/s
Position Repeatability	±0.05 mm
Motor Cable	
Supported Drives	

Mechanical Data	
Stator Diameter	23 mm
Stator Length	242 mm
Stator Mass	450 g
Slider Diameter	12 mm

Special cable KR05-W/R-

KR05-W/R-

Article no.: 0150-3336

Linear Motor robot cable

For LinMot Drives series B1100, E1100 and E1200

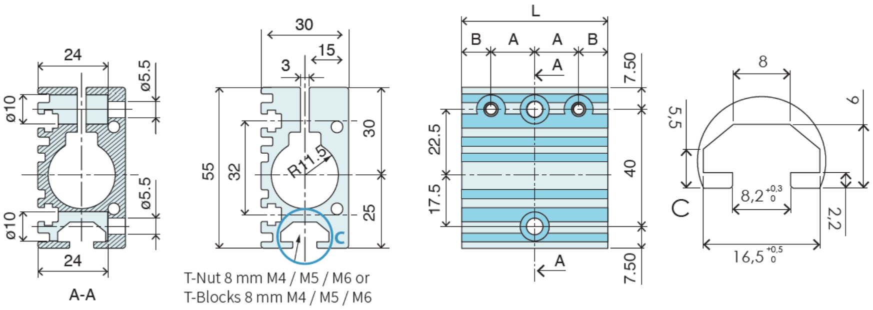
For LinMot Linear Motors with R-connector

Temperature range	-40 ...+80 °C
Materials according to	UL / CSA 300V
Cable diameter	9.7 mm
Cable weight	109 g/m
Max. cable length	30 m
Min. bending radius stationary	40 mm
Min. bending radius moving	80 mm
Torsion moving	270° / 0.5 mm

/ MOTOR FLANGES / LinMot®

PF02-23

Max. torque for clamp plate screws: 4Nm



Item	Stator type	Fan-Assembly Number Standard / Max	L [mm]	A [mm]	B [mm]	Weight [g]	Item-No.
PF02-23x50	P01-23x80	1 / 1	50	15	10	115	0150-2102
PF02-23x120	P01-23x160	1 / 2	120	30	30	280	0150-2103
PF02-23x170	P01-23x160	1 / 2	170	45	40	390	0150-2117
PF02-23 Flange profile per m	P01-23x...	(-)	(-)	(-)	(-)	(-)	0150-2101

Table 12. Comparison of new and previously used Linmot actuators.

		Actuator type	
Parameter	**Unit**	**Type used in previous tests**	**Version bought for current tests**
Type ID		P01-37x240/660x860	PS01-23x160F-R, PL01-12x480/440-LC
Const force	N	53	16
Const force Wfan	N	100	30
Peak force	N	308	86
Stroke	mm	860	270
Peak moment capacity	Nm	134	37
Stator mass	g	1385	450
Stator flange	g	920	390
axel, bearing etc	g	1000	300
Cable (estimated) 3m	g	389	389
Slider mass	g	2227	390
force sensor (estimat)	g	150	100
Total mass estimate	**g**	**6071**	**2019**

CAD drawings with 3D STEP files can be downloaded from the Linmot web-page. For convenience direct links for the components are given in Table 13.

Table 13. Links to CAD drawings for the new actuator system.

Type	Model number	Link to CAD drawing (STEP) and/or further details
Motor (stator)	Linmot PS01-23x160F-R	https://shop.linmot.com/E/ag1000.23.161/linear-motors/linear-motors-p01-23/stators-ps01-23x160/ps01-23x160f-r.htm
Piston (slider)	Linmot PL01-12x480/440-LC	https://shop.linmot.com/index.php?PL01-12x480-440-LC&page=productDetails&productNo=0150-2586&pageType=&source=search&language=E
Cooling flange	Linmot PF02-23x170	https://shop.linmot.com/index.php?PF02-23x170&page=productDetails&productNo=0150-2117&pageType=&source=search&language=E
Cable (15 m)	Linmot KR05-W/R-15	https://shop.linmot.com/index.php?Special%20cable%20KR05-W-R-&page=productDetails&productNo=0150-3336&pageType=&source=search&language=E

One new actuator system has been constructed as shown in Figure 9. The system will be delivered to SSPA on 18 June 2020, such that the model designer can incorporate it in the platform and absorber design.

Only part of the piston needs to go through the motor, and to extend the motion range of the piston extension rods are mounted in both ends of the piston. These extension rods can be shortened (or extended) to fit the new platform and absorber design. Hereby the positions of the baring points can be adjusted to be at suitable structurally good positions at the new model, and the bearing positions does therefore NOT need to match exactly the ones for the previous model (given in Figure 7, Figure 8, Table 8 and Table 9).

When bearing points have been chosen for the new model, the geometry of the system when moving the absorber up and down should be checked in the 3D CAD drawing (similar to Figure 8) to ensure that there are no obstructions to the actuator system (motor, piston, alu-flange, force sensor) within the range of the motion.

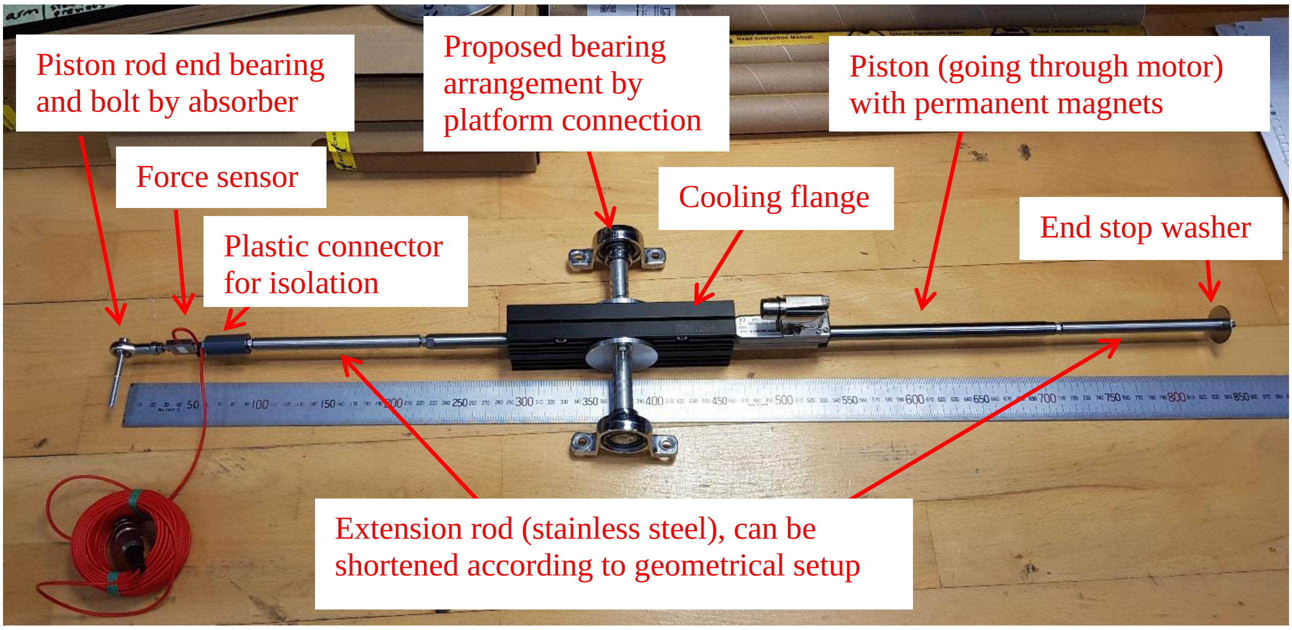


Figure 9. Wave PTO actuator system for current model.

Be aware that the PTO pistons are containing permanent magnets inside. Therefore, keep the pistons clear of magnetic materials and do not drill holes in it.

3 Wave conditions

Wave conditions to be applied are expected to be the same as used in previous recent small-scale testing [6]. The same conditions were also used in the full-scale PTO design [14]. The irregular wave conditions at full-scale are given in Table 14 and the corresponding waves at scale 1:30 are given in Table 15. Waves were generated using a JONSWAP spectrum with peak enhancement factor = 1.5. Further explanations about the source and reason for the 12 irregular seastates termed IR1..IR12 is given in [14]. Due to the limited water depth at AAU (explained in the following Section 4.2) only sea states up to IR10 is planned for the testing at AAU.

Table 14. Full-scale irregular wave characteristics. Only sea states up to IR10 will be tested at AAU.

	IR1	IR2	IR3	IR4	IR5	IR6	IR7	IR8	IR9	IR10	IR11	IR12	Total
H_{m0} [m]	1.05	1.05	1.05	1.05	1.05	2.25	2.25	2.25	3.60	3.60	5.55	7.50	1.96
T_P [s]	6.02	8.22	9.31	10.95	13.69	8.22	10.95	13.69	10.95	13.69	13.69	13.69	10.3
T_{02} [s]	4.47	6.10	6.91	8.13	10.17	6.10	8.13	10.17	8.13	10.17	10.17	10.17	7.6
$T_{-1,0}$ [s]	5.26	7.17	8.13	9.56	11.95	7.17	9.56	11.95	9.56	11.95	11.95	11.95	9.0
L_{0p} [m]	56.7	105.5	135.5	187.5	293.0	105.5	187.5	293.0	187.5	293.0	293.0	293.0	175
s_{0p} [-]	0.019	0.010	0.008	0.006	0.004	0.021	0.012	0.008	0.019	0.012	0.019	0.026	0.012
Probability	0.12	0.11	0.12	0.12	0.09	0.08	0.12	0.04	0.12	0.07	0.03	-	1.0
P_{wave} [kW/m]	2.8	3.8	4.3	5.1	6.3	17.4	23.2	29.0	59.4	74.3	176.6	322.5	25.7
Energy part	1.25%	1.57%	1.98%	2.27%	2.13%	5.51%	10.78%	4.47%	27.59%	19.07%	23.37%	-	100%

Table 15. Small-scale (1:30) irregular wave characteristics. Only sea states up to IR10 will be tested at AAU.

	IR1	IR2	IR3	IR4	IR5	IR6	IR7	IR8	IR9	IR10	IR11	IR12	Total
H_{m0} [m]	0.035	0.035	0.035	0.035	0.035	0.075	0.075	0.075	0.120	0.120	0.185	0.250	0.065
T_P [s]	1.10	1.50	1.70	2.00	2.50	1.50	2.00	2.50	2.00	2.50	2.50	2.50	1.88
T_{02} [s]	0.82	1.11	1.26	1.48	1.86	1.11	1.48	1.86	1.48	1.86	1.86	1.86	1.40
$T_{-1,0}$ [s]	0.96	1.31	1.48	1.75	2.18	1.31	1.75	2.18	1.75	2.18	2.18	2.18	1.64
L_{0p} [m]	1.89	3.52	4.52	6.25	9.77	3.52	6.25	9.77	6.25	9.77	9.77	9.77	5.83
s_{0p} [-]	0.019	0.010	0.008	0.006	0.004	0.021	0.012	0.008	0.019	0.012	0.019	0.026	0.012
Probability	0.12	0.11	0.12	0.12	0.09	0.08	0.12	0.04	0.12	0.07	0.03	-	1.00
P_{wave} [W/m]	0.564	0.769	0.872	1.026	1.282	3.533	4.710	5.888	12.058	15.073	35.824	65.420	5.20
Energy part	1.25%	1.57%	1.98%	2.27%	2.13%	5.51%	10.78%	4.47%	27.59%	19.07%	23.37%	-	100%

A total of 28 regular sea states are used as defined in Table 16. The first 16 waves has increasing frequency and constant wave height. The last tests are for the frequencies 0.5, 0.7 and 1.0, where the wave height is increased to have 5 different wave heights for each frequency (2, 4, 6, 8, 10 cm).

Table 16. Characteristics of regular waves.

	Lab-scale (1:30)			Full-scale		
Number	Frequency	Period	Height	Frequency	Period	Height
No	*f*	*T*	*H* target	*f*	*T*	*H* target
-	Hz	s	m	Hz	s	m
1	0.40	2.500	0.04	0.07	13.69	1.20
2	**0.50**	**2.000**	**0.04**	**0.09**	**10.95**	**1.20**
3	0.60	1.667	0.04	0.11	9.13	1.20
4	**0.70**	**1.429**	**0.04**	**0.13**	**7.82**	**1.20**
5	0.80	1.250	0.04	0.15	6.85	1.20
6	0.85	1.176	0.04	0.16	6.44	1.20
7	0.90	1.111	0.04	0.16	6.09	1.20
8	0.95	1.053	0.04	0.17	5.77	1.20
9	**1.00**	**1.000**	**0.04**	**0.18**	**5.48**	**1.20**
10	1.05	0.952	0.04	0.19	5.22	1.20
11	1.10	0.909	0.04	0.20	4.98	1.20
12	1.15	0.870	0.04	0.21	4.76	1.20
13	1.20	0.833	0.04	0.22	4.56	1.20
14	1.30	0.769	0.04	0.24	4.21	1.20
15	1.40	0.714	0.04	0.26	3.91	1.20
16	1.50	0.667	0.04	0.27	3.65	1.20
17	1.00	1.000	0.02	0.18	5.48	0.60
18	1.00	1.000	0.06	0.18	5.48	1.80
19	1.00	1.000	0.08	0.18	5.48	2.40
20	1.00	1.000	0.1	0.18	5.48	3.00
21	0.70	1.429	0.02	0.13	7.82	0.60
22	0.70	1.429	0.06	0.13	7.82	1.80
23	0.70	1.429	0.08	0.13	7.82	2.40
24	0.70	1.429	0.1	0.13	7.82	3.00
25	0.5	2.000	0.02	0.09	10.95	0.60
26	0.5	2.000	0.06	0.09	10.95	1.80
27	0.5	2.000	0.08	0.09	10.95	2.40
28	0.5	2.000	0.1	0.09	10.95	3.00

4 Test setup at AAU

Tests will be performed in the wave basin at the Department of the Built Environment, Aalborg University (AAU), [15] https://www.en.build.aau.dk/laboratories/ocean-and-coastal-engineering/. General information about the wave basin and the installation of the model (including instrumentation) is presented in this chapter.

4.1 AAU wave basin layout

The wave basin is 14.6 m x 19.3 m x 1.5 m (length x width x depth) with an active test area of 8m x 13m (length x width, basin is wide). The basin is equipped with long-stroke segmented piston wavemakers for accurate short-crested (3-dimensional) random wave generation with active absorption. A photo of the wave basin is given in Figure 10. Further information is given in [15] & [16]and additional details are given in Appendix A.

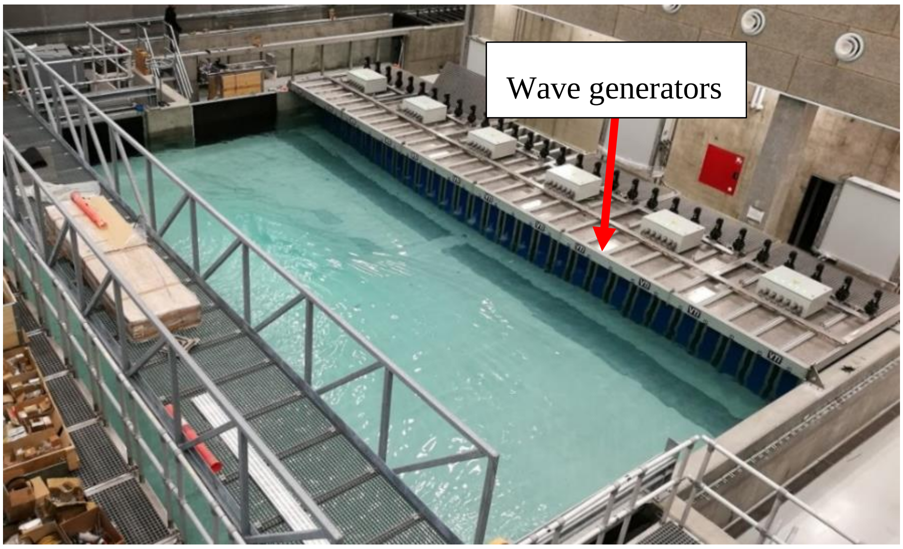


Figure 10. Wave basin at Aalborg University.

To indicate the size, a photo of the previous scale 1:30 model is given in Figure 11 (this model was just a half of a P80 model).

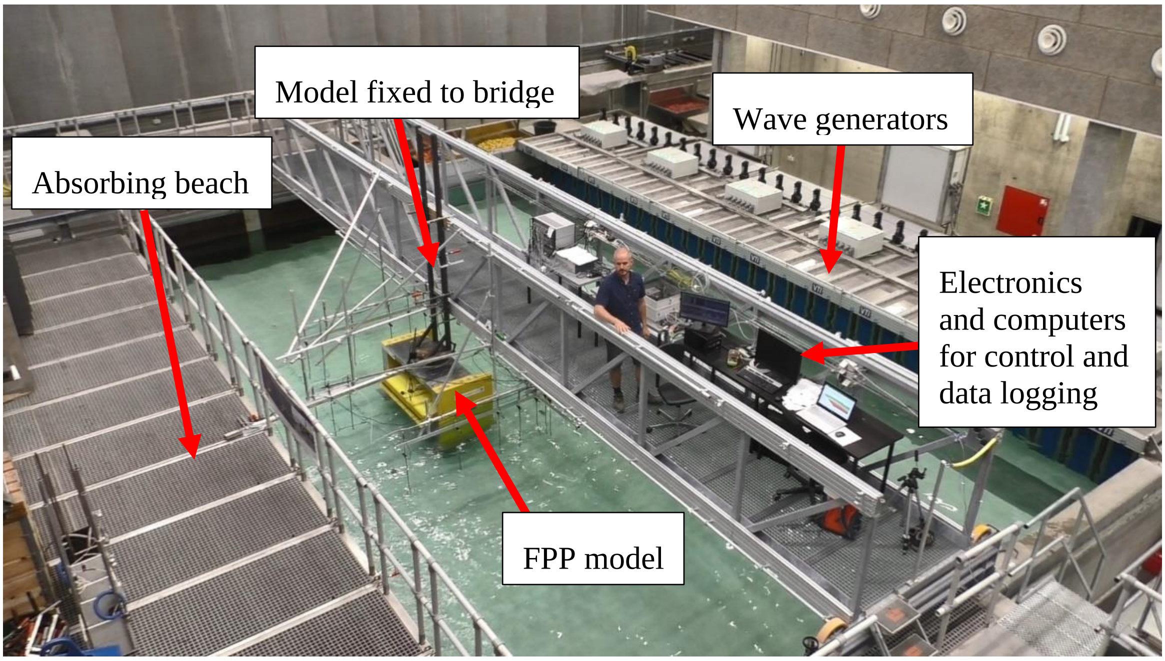


Figure 11. Photo of former FPP model in basin at Aalborg University (Absorber Mark IV, December 2018).

The new model should be placed in the centre of the basin along the width, i.e. with the same distance to the basin side-walls. The distance along the length is to be decided based on the mooring lay-out, but assuming the centre is chosen as the mooring point the layout will be as indicated in Figure 12, thereby leaving 4 meters in horizontal direction for the mooring both in front and behind (fore and aft) the mooring point, and 6.5 meters to both sides (port and starboard).

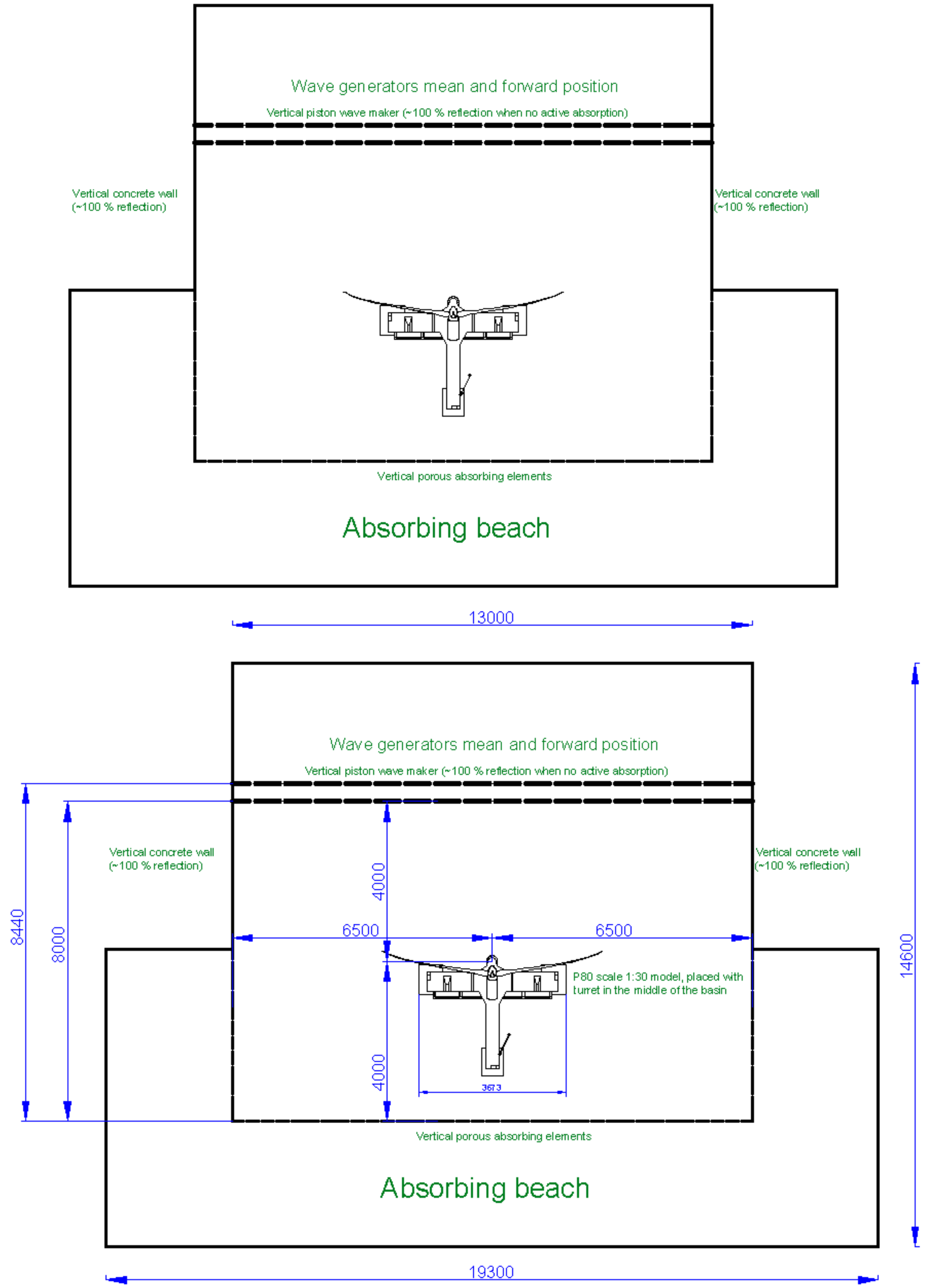


Figure 12. Sketch of FPP model placed in basin at Aalborg University. Lower sketch with measures in mm.

4.2 Water depth at AAU

The water depth has been decided based on the following:

1) Water depth should be as high as possible to make it match the full scale condition the best
2) Water is not allowed to overtop the sidewalls in the basin (the highest wave crests should not overtop the 1.5 m high side walls)
3) Water depth should be sufficiently high and sea states sufficiently mild, to avoid the motion of the device making the model hit the floor of the basin

It has been chosen that a higher water depth is more important than the possibility to generate higher waves. Small operational sea states are of main interest, so generation up to full scale *Hs* = 3.6 m is considered sufficient (wave generator is capable of generating much higher waves).

Water depth in the tests will be 1.2 m. A sketch is given in Figure 13. The water depth will allow for generation of small operational sea states without overtopping the side walls in the basin as explained in the following.

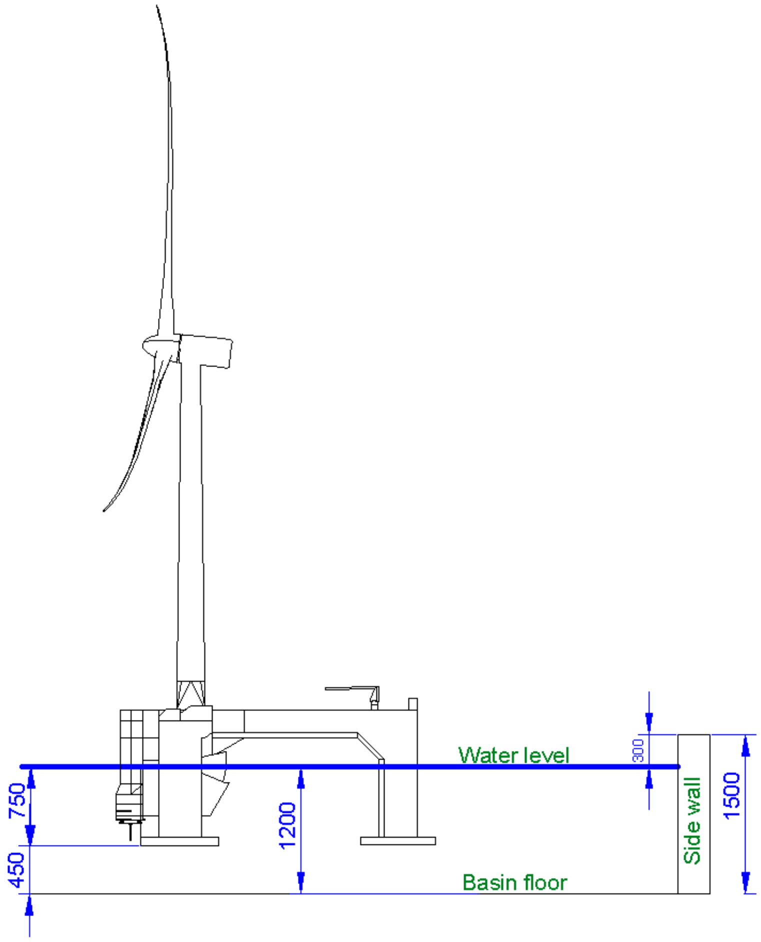


Figure 13. Sketch of FPP model placed in basin at Aalborg University at water depth 1.2 m. Measures in mm.

4.3 Study of motions and risk of model hitting basin floor

A dedicated study has been performed in [17] to investigate the motion of the platform in the AAU basin. The distance between the model bottom and the basin floor was analyzed using platform RAO's for moderate operational sea states taking into account pitch and heave platform motions. The conclusion was that there is no risk of the platform hitting the basin floor, and still plenty of room for further downward motion before there will be a risk of collision [ibid.].

4.4 Wave and water level conditions at AAU

The main limiting factor for the AAU facility is that the P80 model is relatively large compared to the AAU basin size. As the P80 is intended for deep water depths (~120 m), the correct water depth cannot be achieved in the AAU basin with the given size of the model.

With the highest wave conditions being IR10 the lowest expected freeboard on the basin walls is estimated to be 11 cm as given in Table 17. This leaves a little margin to take into account the influence of reflected and radiated waves. In summary the model scale water depth of 1.2 m (full scale 36 m) is considered the best possible condition (the highest possible water depth).

Table 17. Characteristics of highest wave and freeboard to top of basin wall.

Parameter	Full scale	Small scale	Notes
Water depth (m)	36.0	1.2	
Significant wave height (m)	3.60	0.12	Max wave to be tested is IR10
Maximum wave height (m)	7.20	0.24	Estimated as 2*Hs
Maximum crest height (m)	5.76	0.19	Estimated as 0.8*Hmax
Maximum water elevation from floor (m)	41.76	1.39	Water depth + maximum crest height
Freeboard to wall-top (m)		0.11	Wall height - max elevation

In Figure 14, the required wave theory for both the regular and irregular sea states presented in Chapter 3 are shown for the intended water depth of 120 m (blue markers), and the highest possible water depth for the experiments at AAU, 36 m (red markers). Utilizing the required wave theory as per this diagram, the error of the maximum velocities and accelerations are less than 1% (i.e. the lines in the diagram are established using this criteria). The difference in water depth does not alter the required wave theory from this diagram. However, the sea states are shifted from deeper water to more intermediate regime (deep water in the diagram is defined by d/L>1/2 and shallow water is when d/L<1/20). For the irregular sea states $H = H_{m0}$ and $T = T_p$ is used for the circular markers in Figure 14.

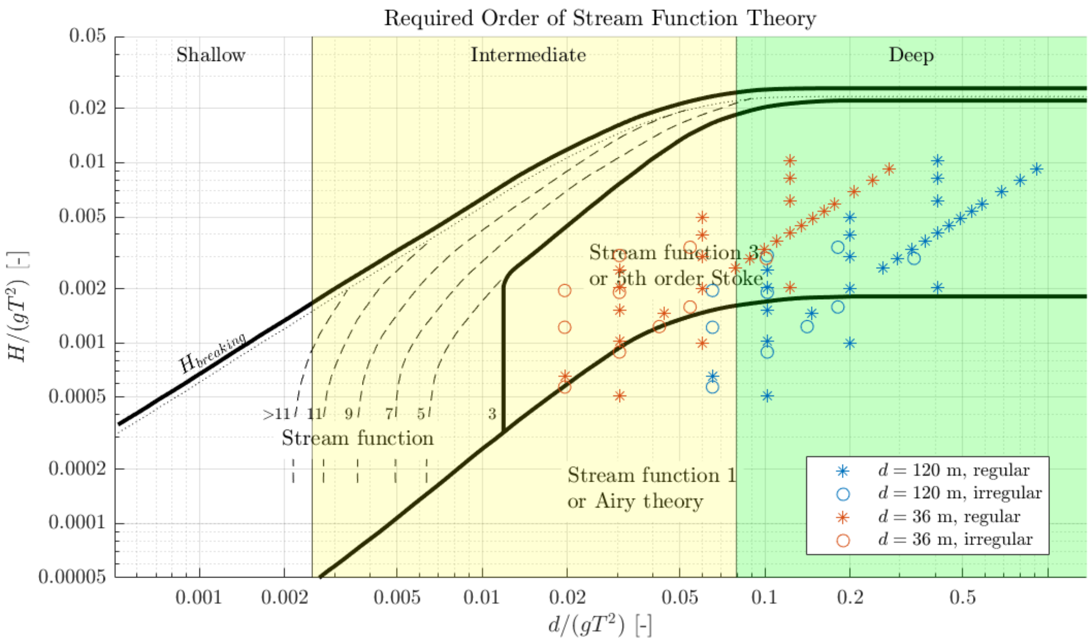


Figure 14. Wave theory validity based on DNV-RP-C205 [18]. *d* is water depth, *H* is wave height, *T* is wave period.

From Figure 14, it is decided to generate regular waves by approximate stream function wavemaker theory by [19] with a minimum order of 3. Irregular waves are generated by second order wavemaker theory by [20] with the modification by [21] and with active absorption by [22] activated.

5 Test programme

The present chapter is separated into the tests to be performed at the different facilities as introduced in Chapter 1.2, Table 2. The contents of this section are intended to give an overview of the test conditions and purposes, whereas details and the complete list of individual tests will be elaborated in Excel sheets at a later stage.

5.1 Pre-tests to make as-built CAD drawing

Drawings and specifications of the model will be made by the model designer. However, the as-built model will obviously deviate from the target with differences in both mass and dimensions. As the intention is to use the model for numerical model validation it is of paramount importance that uttermost care is taken to measure the as-built mass and geometry of the individual components. Differences in mass of the individual components should be accounted for in making a 3D CAD as-built drawing by adjusting the material density to get a match in mass between the drawing and the measured weight.

5.2 AAU tests: Basic performance and simple tests

The basin at AAU is described in Appendix A. At AAU basic investigations are performed to ensure correct model performance such as to validate flotation level, working WT, working WEC & PTO. Further simple initial tests are performed like decay, non-combined simple wave tests, current tests, wind-tests. Tests will be performed in the shallow water basin as described in Chapter 0, and the overall plan is given in Table 18.

Table 18. Tests at AAU, basic performance and simple tests.

Description	Purpose
Dry tests on wave PTO	To ensure correct function of actuators, control system etc. Completed in dry conditions before the basin access starts
Checking flotation of model	Adjustment of draft/trim/heel by ballasting. Measurement of rest angles of absorbers. Adjustment of CAD drawing to match.
Checking sensors and data acquisition	Calibrate and check all signals for errors
Hydrostatic stiffness test	Pull tests to measure hydrostatic stiffness (no mooring)
Mooring response test	Pull tests to measure mooring force response curves
Decay	Pull out and release tests on absorbers and platform. For numerical model validation
Waves only	Calibration of sea states in basin without device
Constant wind tests	Checking WT performance, validating numerical model response
Fixed absorbers tests	Measurements in waves where the absorbers are locked to the platform using mechanically locked PTO cylinders
Absorber radiation tests with free platform	Measurements without incident waves where the WEC PTO’s are moving the absorbers
Absorber radiation tests with platform fixed in yaw	As above, but where the platform is restricted to rotate in yaw using two stern lines (measure the forces in the lines, thereby the yawing moment)
Free motion in head-on waves	Motion in waves with inactive PTO for both WT and WEC
Non head-on waves	Fixed heading of device by stern lines. Purpose to gain experience with the use of stern lines
Current only test	Initial tests with current in basin (measurement of motion of device)
WEC in operation	Power performance tests in waves with inactive WT
WT in operation	Motions and forces for static wind forces (inactive WEC)
WT & WEC in operation	Initial demonstration tests with combined wind and waves (and possibly also current)

5.3 SSPA tests: Detailed towing and wave tests

The basin and towing tank at SSPA are described in Appendix B. At SSPA the following detailed tests will be performed: Towing tests will be performed in the towing tank, whereas wave tests and combined wave and possibly towing tests will be performed in the wave basin. Tests in the basin will be performed at the correctly scaled water depth.

5.3.1 Towing Tank tests at SSPA

The plan for tests in the towing tank is given in Table 19.

Table 19. Tests at SSPA, towing tank.

Description	Purpose
Platform with absorbers locked at rest position, towed at different headings and speeds	To obtain Cd for different headings in operation
Platform with absorbers locked at lowest position, towed at different headings and speeds	To obtain Cd for different headings in survival

5.3.2 Wave basin tests at SSPA

Instead of applying currents the basin allows towing through the MDL basin simultaneous to wave generation by dragging the whole setup (mooring anchors will be dragged) through the basin. If this option is going to be used the length of the tests is limited by the time it takes to drag the setup from one end of the basin to the other. As a main reason for doing tests is to get knowledge about 2nd order effects (drift forces) it might be unrealistic to get long enough test lengths to get reasonable measurements. It is unknown how long test lengths that can be achieved in the basin if towing is utilised, so the planning of this is at the time of writing still outstanding.

A preliminary plan is given in Table 20. The plan is to be elaborated further in collaboration with SSPA. The wind turbine might also be part of the tests at SSPA, but at the time of writing this is also a subject for further planning and agreements.

Table 20. Preliminary ideas for tests at SSPA, wave basin.

Description	Purpose
Empty basin with waves	Calibrate Waves
Platform with absorbers locked at lowest position, with large waves	Mooring forces
Decay tests	Pull out and release tests on absorbers and platform. Model validation at the deeper water depth. Comparison to the low depth used in the AAU tests
Mooring response tests	Pull tests to measure mooring force response curves
Wave only tests for fixed heading of P80 (fixation with stern lines). Both tests with absorbers locked and moving	Numerical model validation with influence of wave heading, e.g. 0 deg, 15 deg and 30 deg heading.
Wave only tests for free weather vaning of P80 (without stern lines)	Numerical model validation

5.4 Tests at large facility/IH Cantabria: Combined wind, wave, current

Detailed tests at large water depth with combined currents, waves and winds. Focus on WTG control and platform interaction. Plan is yet to be completed.

6 References

[1] FPP (2020). "Design Freeze 1 Summary Document", Document no. 100-FPP-101-Z-TN-0067. Revision date: 5.5.2020. Confidential FPP document.

[2] Andersen, M. T. (2016). "Floating Foundations for Offshore Wind Turbines", PhD Dissertation, Faculty of Engineering and Science, Aalborg University, Aalborg University Press, ISSN (online): 2246-1248, ISBN (online): 978-87-7112-816-1.

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Appendix A: AAU wave basin

Welcome to the Ocean and Coastal Engineering Laboratory

- an integrated part of the research and teaching at the
Department of the Built Environment, Aalborg University

At the Ocean and Coastal Engineering Laboratory, we have created a modern, flexible laboratory with state-of-the-art equipment. We are located on the ground floor of the Department of Civil Engineering and are visible from several locations in the building. The research group has more than 30 years of research experience related to physical model testing and have developed advanced model testing techniques to test ports, coastal structures, offshore structure, wave energy converters etc.

The wave basin is 14.6 m x 19.3 m x 1.5 m (length x width x depth) with an active test area of 13 x 8 m. A deep water pit with size 6.5 m x 2.0 m with up to 6 m extra depth is available. The basin holds up to approximately 400 m3 water (400.000 liters) and accommodates testing on deep and shallow water. The basin is equipped with long-stroke segmented piston wavemaker for accurate short-crested (3-dimensional) random wave generation with active absorption and pumps for currents.

The wave flume is 22.1 m x 1.5 m x 1.5 m (length x width x depth) and equipped with long-stroke piston wavemaker for random wave generation and active absorption.

The wavemakers are powered by electric motors, which allows for less acoustic noise, no oil pollution in the basin and more accurate waves. Our water treatment system in the basement enables us to reuse the water from one test to the next. This makes a more operational/efficient laboratory and minimizes the environmental impact.

The equipment

Wave and current generation system for basin

- 13 x 1.5 m (width and height).
- 30 individually controlled wave paddles (snake type configuration) powered by electric motors.
- Accurate generation of 3D waves due to narrow vertically hinged paddles (0.43 m segment width).
- Maximum wave height up to 45 cm (at 3 s period).
- Typical maximum significant wave height in the range of 0.25-0.30 m
- Built with stainless steel and fibreglass for minimum maintenance.
- Pumps with a total maximum flow of 3500 m3/h for generation of strong current in the basin (up to 0.15 m/s at 0.5 m water depth). Structures can be tested in combined waves and current (following or opposing).

Wave and current generation system for flume

- 1.5 x 1.5 m (width and height).
- Single-element wave generator powered by electric motors.
- Exact generation of 2D waves.
- Maximum wave height up to 65 cm (at 3 s period).
- Built with stainless steel and fibreglass for minimum maintenance.
- Pumps with a total maximum flow of 1100 m3/h for generation of strong current in the flume (up to 0.4 m/s at 0.5 m water depth). Structures can be tested in combined waves and current (following or opposing).

Passive wave absorber elements

- For absorption of waves in the wave basin and wave flume.
- Built with stainless steel and hot galvanized stretch metal sheets for minimum maintenance.

Water treatment system

- Contains sand filters and UV filters.
- Reuses the water in the reservoir.
- Automatic fast filling to specified water depth and fast emptying of the facilities (adjustable speed)

Wave generation software

- In-house deigned AwaSys software utilizing state-of-the-art wave generation principles (used by more than 25 labs)
- Generation of regular, irregular, solitary waves
- 2-D and 3-D active wave absorption (reflection compensation)
- 2nd order irregular unidirectional and multidirectional wave generation

Wave analysis software

- In-house deigned WaveLab software for data acquisition and wave analysis (used by more than 20 labs)
- Data acquisition system that support simultaneous sampling of 80 channels at more than 1 kHz sampling rate
- Reflection separation of linear and nonlinear 2-D waves
- Directional wave analysis of short-crested waves using BDM and MLM methods

Other equipment

- More than 40 resistance type wave gauges including electronics
- Large selection of pressure transducers and load cells
- Various equipment for measurement of flow velocities (lasers, ADV, etc.)
- Laser profiler for automatic profiling of scour holes and surfaces of rubble mound structures
- Qualisys Mocap Oqus 700+ 4 camera motion capturing system
- OptiTrack Flex 13 object tracking system
- Step gauge for run-up measurement
- Large selection of breakwater armour units

Special requirements

Operation of the laboratory requires participation of technicians or scientific personnel from the facility.

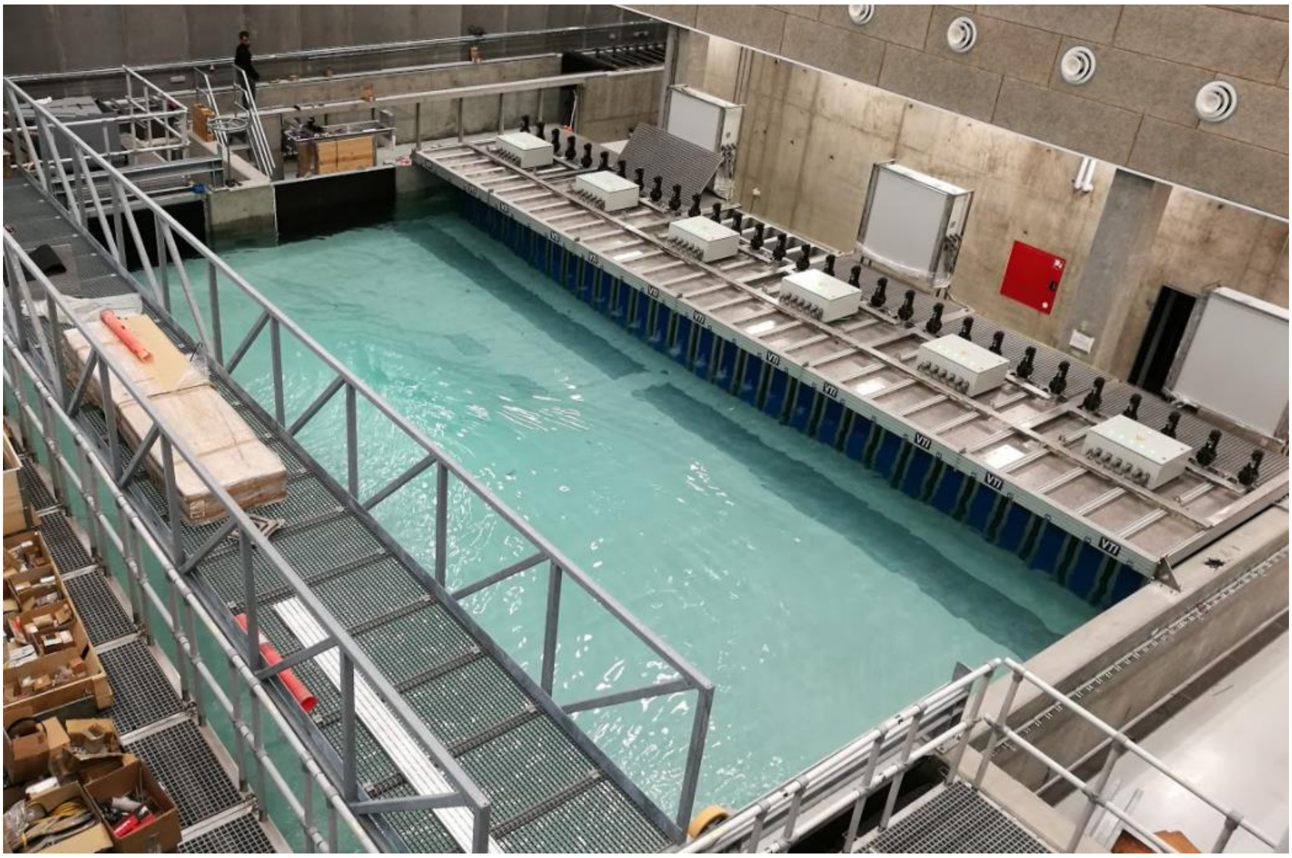
Staff

Leader of laboratory/Contact Person

Jens Peter Kofoed, +45 9940 8474, jpk@build.aau.dk
Thomas Lykke Andersen, +45 9940 8486, tla@build.aau.dk

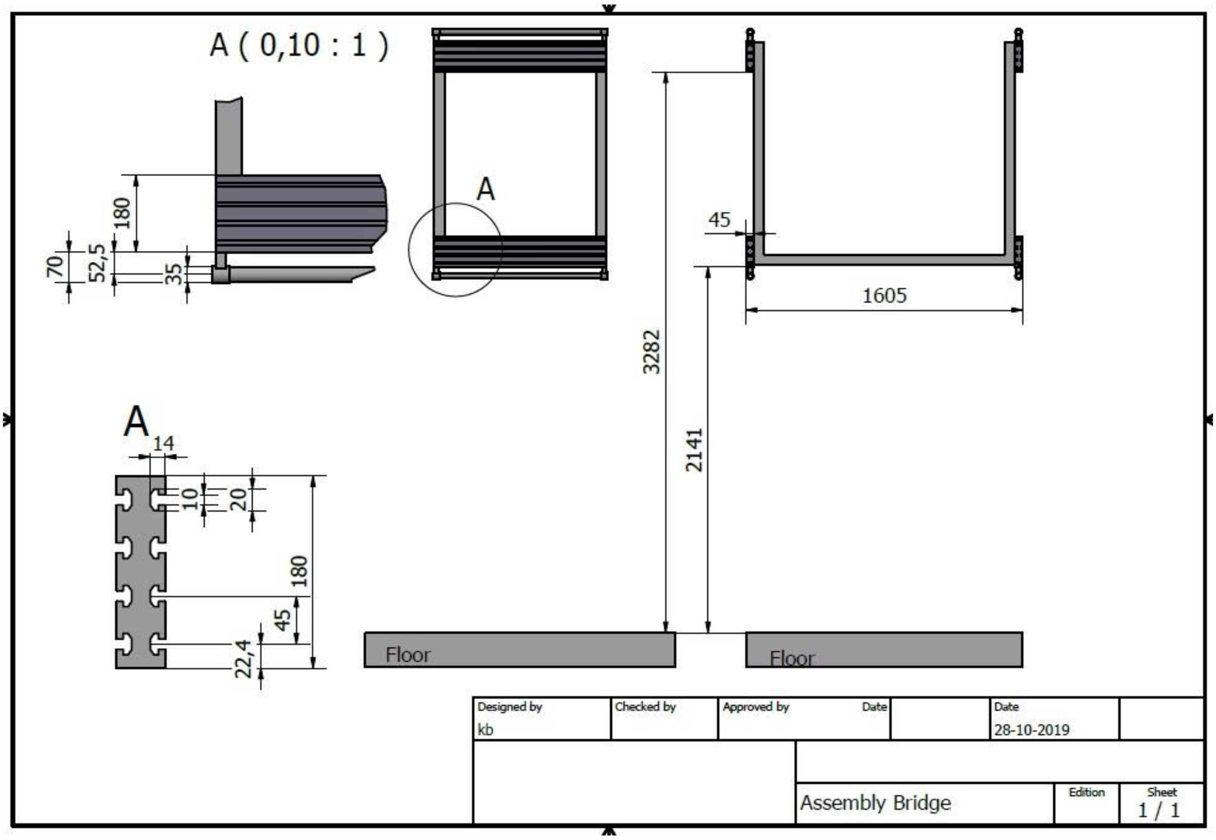
Other key staff

Amélie Tetu, +45 9940 2924, amt@build.aau.dk
Nikolaj Holk, +45 9940 8558, nh@build.aau.dk



The lab getting ready (01.06.2017).

Testing of breakwater for Port of Hanstholm (19.01.2018).



Mounting details and dimensions

Appendix B: SSPA Facilities

The scaled model will be tested in the towing tank and the wave basin at SSPA. In addition to this, SSPA has facilities to determine the centre of gravity and moments of inertia of the model.

Towing Tank

The towing tank is large, and frequently used for fairly large-scale vessels (up to around 7 m). The capabilities of the carriage are therefore not likely to be a limitation for the P80 scaled model. A photo of the tanks can be seen in Figure 15 and the corresponding specifications in Table 21.

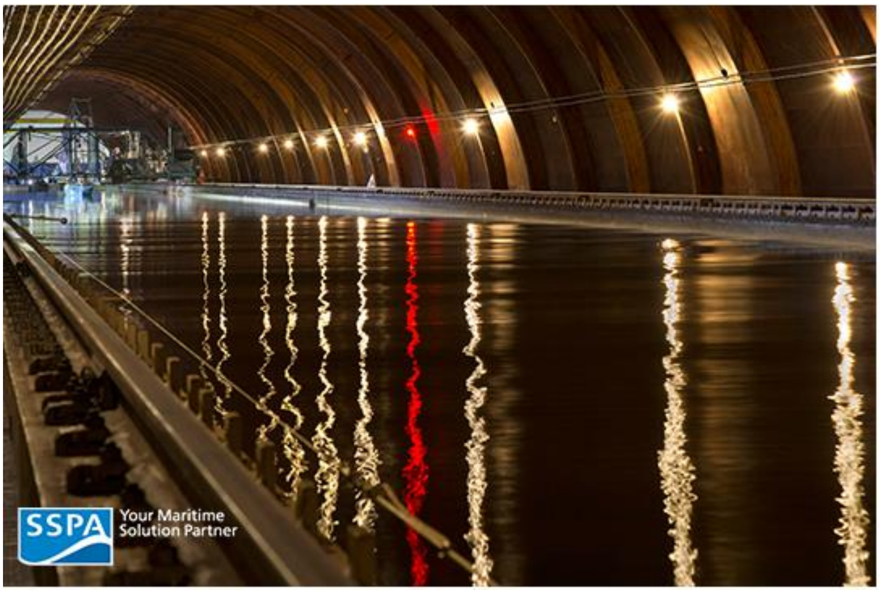


Figure 15: Photo of the SSPA towing tank

Table 21: Dimensions and specifications of the SSPA towing tank

Basin	L x B x D	260 x 10 x 5 m
Carriage	Speed Speed accuracy	0 - 11 m/sec ± 0.001 m/sec
Waves	Wave length Wave height Frequencies	0.4 < lambda < inf. m 0 < H < 0.3 m 0 < f < 2 Hz

Maritime Dynamics Laboratory (MDL)

The SSPA basin used within this project is called the Maritime Dynamics Laboratory (MDL). A photo of MDL can be seen in Figure 16 and the corresponding specifications in Table 22. Whilst the basin does have the capabilities to include current, it is known to be turbulent and has therefore not been used for many years. It is therefore recommended by SSPA to represent the effects of current by moving the device through the water. This is achieved by mechanically dragging the anchor points in a given direction.

Figure 16: Photo of the SSPA basin known as the Maritime Dynamics Laboratory (MDL)

Table 22: Specifications of the SSPA basin known as the Maritime Dynamics Laboratory (MDL)

Basin	Dimensions Water depth Deep-water pit	88 × 39 × 3.5 m 0 - 3.2 m 5 × 9 m, depth 8 m
Waves	Wave length Wave height Frequencies	0.2 < L < inf. m 0 < H < 0.4 m 0 < f < 3 Hz
Wind	Speed approx.	0 - 10 m/sec
Current	Towing up to 3.5 m/sec ~~Pump system up to 1.0 m/sec~~	
Carriage	Motion x’0 y’0 ψ’0	Speed ± 3.50 m/sec ± 3.00 m/sec ± 30 °/sec